frost warnings were again issued for upper Michigan and northern and western lower Michigan, and the warnings were partially verified. On the 30th frost warnings were issued for eastern upper Michigan, lower Michigan, Indiana, and northern and central Ohio and were fully verified, except over northern Michigan. At this time (31st) high pressure and low temperature prevailed over the Ohio Valley and frost warnings were therefore issued for the eastern and southern portions of West Virginia, but they were apparently not verified.

Chicago District.—Frost warnings were issued for the cranberry marshes of Wisconsin on the 18th, 24th, 25th, 26th, 27th, 29th, and 30th; also, on the 28th, frost being indicated for the night of the 29th–30th, an advisory warning was issued apprising the cranberry growers of that fact, so as to prevent the water being drawn off from the bogs on the 28th. The warnings of the 18th, 26th, 27th, 28th, and 29th were fully verified, while that of the 30th was partially verified.

Warnings of light frost in exposed places of the lowlands of the tobacco region of Wisconsin were issued on the 24th, but cloudiness prevented frost formation. No special warnings were sent to the tobacco region after the 24th, due to the fact that this office was informed on the 25th that tobacco cut within about 10 days of that date would be a total loss, as the crop was immature on account of the unusually cool summer.—*Chas. L. Mitchell, Asst. Forecaster.*

Frost warnings for the several States were issued as follows: 24th—exposed places in northeastern Minnesota; 25th—northern Minnesota and northeastern North Dakota; 26th—eastern North Dakota, north and central Minnesota, and lowlands of Wisconsin; 28th—North Dakota, northwestern Minnesota, extreme northern South Dakota, and northwestern Wyoming.

The warning of the 24th failed of verification, while that of the 25th was fully, and those of the 26th and 28th were partially verified.

The storm warnings in the New Orleans district are covered in the special report on the West Indian storm. No special warnings were issued in the Denver (Colo.), San Francisco (Cal.), and Portland (Oreg.) districts, except in the latter, where "fire wind" forecasts were issued to advantage on the 18th, 19th, 20th, and 21st.

THE TROPICAL STORM OF AUGUST 10, 1915.

By H. C. FRANKENFIELD, Professor of Meteorology.

[Dated: Weather Bureau, Wash., Sept. 25.]

SOME HISTORICAL DATA.

Records of West Indian hurricanes are available, at least as to time and locality of occurrence, as far back as 1493, and from that year to the present 492 storms were noted, an average of little more than one each year. The great storms that reached the United States were, of course, not very numerous, yet they occurred with sufficient, though very irregular, periodicity to warrant the reasonable expectation of one every few years. Severe tropical storms visited Galveston in the years 1834, 1837, 1847, 1854, 1866, 1867, 1875, 1886, 1900, 1909, and 1915, and those of 1900 and 1915 were by far the most violent. The more severe tropical storms of recent years in the United States were:

1. The Atlantic coast storm of August, 1873.
2. The Atlantic coast storm of September, 1874.
3. The Texas storm of September, 1875.
4. The Atlantic coast storm of September, 1876.
5. The Atlantic coast storm of October, 1877.
6. The Atlantic coast storm of September, 1878.
7. The Atlantic coast storm of October, 1878.
8. The Atlantic coast storm of August, 1879.
9. The South Atlantic coast storm of August, 1881.
10. The Gulf and Atlantic coast storm of September, 1882.
11. The Atlantic storm of September, 1883.
12. The South Atlantic coast storm of August, 1885.
13. The Texas coast storm of August, 1886.
14. The Atlantic coast storm of November, 1888.
15. The Atlantic storm of September, 1889.
16. The South Atlantic coast storm of August, 1893.
17. The Gulf storm of October, 1893.
18. The Atlantic coast storm of October, 1894.
19. The Atlantic coast storm of September, 1896.
20. The Porto Rico storm of August, 1899.
21. The Galveston storm of September, 1900.
22. The Gulf storm of August, 1901.
23. The Florida storm of September, 1903.
24. The Gulf storm of September, 1906.
25. The South Atlantic storm of October, 1906.
26. The west Gulf storm of July, 1909.
27. The Gulf storm of September, 1909.
28. The Atlantic storm of October, 1909.
29. The Atlantic storm of October, 1910.
30. The South Atlantic storm of August, 1911.
31. The Gulf storm of August, 1915.

ORIGIN OF TROPICAL STORMS.

The causation of tropical storms is somewhat a matter of conjecture and theory. The subject has been more or less fully discussed by many writers, but nothing has been evolved in very recent years that is in conflict with the theory advanced by Prof. F. H. Bigelow,[1] which is as follows:

> Hurricanes occur in the southeastern parts of the United States and adjacent waters during the season of the year when the cooling of the Northern Hemisphere takes place as the sun retreats toward the Southern Hemisphere. At this season the calm belt of the Tropics and the heated, moist condition of the air in the region known as the doldrums are at their farthest northern limit. The South Atlantic permanent anticyclone, which lies over the subtropical ocean, is in its fullest vigor. Now, superposed upon these states of the lower atmosphere, the colder temperatures of the upper atmosphere, caused by the approaching autumn, on account of the more rapid circulation higher up, overspread the tropic strata near the surface. As the polar air cools first, it flows gradually above the warmer air at the south of it near the ground, and covers it with a circulating sheet of temperature cool or low for the time of year. The effect of all this is to make the atmosphere unstable, that is to say, too warm at the bottom, compared with that above it, to be able to maintain the usual equilibrium. The tendency is, therefore, for the lower air to rise vigorously and burst its way upward by convection, in order that the normal equilibrium may be restored. Of course, this action is favorable to the formation of cyclonic gyrations and the development of severe storms. Hurricanes seem to generate in some such way as this, though our observations are as yet inconclusive on that point, since there is always observed to be a stagnant, warm condition over the ocean at the time the incipient cyclonic action begins. It is to be especially considered that the isotherms in hurricanes do not show any very decided differences in temperature on opposite sides of the center, such as always prevail in the cyclones of the north. There are no counter-flowing currents here, and no source is known from which these can arise in the equatorial region to produce the marked temperature gradients found in cyclones. Furthermore, hurricanes are much more circular in shape and conform more exactly to the pure theory of cyclones as derived from the mathematical analysis.

A very large majority of the hurricanes of which there is record, occurred during the autumn or pre-autumn season, in accordance with the above, but a considerable number occurred in July, and some during the earlier months of the year, even in the winter. These, however, were probably due to some intensification of the usual contributory causation, and were not in conflict with the general idea. Again, the hurricanes of the winter, spring,

[1] Features of Hurricanes, by Prof. F. H. Bigelow. Year Book, Department of Agriculture, 1898.

and early summer are not usually of marked character, although some of the July ones were as violent as those of the autumn.

As to the place of origin of tropical storms, it is probably best to quote again, this time from the late Prof. E. B. Garriott: [2]

Aside from the fact that they commonly emerge from the region of equatorial rains, which lies between the Lesser Antilles and the African coast, little is known regarding the place of origin of West Indian hurricanes. It has seemed allowable in instances to assume that storms which have been encountered by vessels far to the eastward of the Lesser Antilles have subsequently visited the West Indies, but owing to the very meager amount of data which has been received from the tropical ocean such assumptions are not susceptible of definite proof. It is not improbable, however, that some of the West Indian hurricanes originate over the mid-Atlantic tropics and even well over toward the Cape Verde Islands. The latitudinal limits of the region within which these storms originate may be safely represented by the parallels of 8° and 20° north, and it is believed that they have their origin along the line of the southern limit of the northeast trades. As the summer advances the North Atlantic area of high barometer settles southward over the eastern Atlantic, forcing the limit of the trade winds southward, and causing hurricanes to form farther and farther to the westward until October, when they develop or originate over the eastern Caribbean Sea or but a little distance east of the Lesser Antilles.

Later years have added but little of value to our knowledge of the subject. Those who desire detailed information as to hurricanes and their paths are referred to the publications of Profs. Bigelow and Garriott, earlier mentioned, and also to the works of Prof. Oliver L. Fassig [3] of the Weather Bureau, and of Father Benito Viñes.[4]

PATHS OF TROPICAL STORMS.

The paths of tropical storms roughly follow the general atmospheric circulation, from east to west in the Tropics and from west to east in the more northern latitudes. They usually pursue a west to northwest path, recurve, and then move northeastward. Many, of course, do not recurve at all and are dissipated. As to the point of recurving, it appears to be well to again quote from Prof. Garriott: [5]

The recurve of storms in the West Indies and over the Gulf of Mexico is dependent upon general meteorological conditions, and more especially upon the distribution of atmospheric pressure. The anticyclonic or high-pressure area of the North Atlantic Ocean lies northeast of the West Indies, and causes east to northeast winds over the southern part of the ocean and the Caribbean Sea. The storms that develop in the region east of the West Indies, and also those of a more western origin, have a tendency to follow the course of the main equatorial current over the Caribbean Sea. This course is doubtless largely influenced by the general drift of the atmosphere in that region, and, following the anticyclonic circulation of winds, the hurricanes skirt the western quadrants of the Atlantic high area, and, carried by the general drift of the atmosphere, follow paths which recurve north and northeastward near the southeastern coasts of the United States. As a majority of the hurricanes traced followed the course indicated, it may be considered the usual course of West Indian storms when the usual meteorological conditions obtain over the southern and southwestern North Atlantic Ocean and the eastern part of the United States. Some of the more important storms that originate near the West Indies do not recurve to the northward, but move westward over the Gulf of Mexico and dissipate over Mexico or the Southwestern States. In such cases high barometric pressure to the northward apparently prevents a recurve.

According to Prof. Fassig's computations the mean paths for June and July originate between latitude 10° and 15° N., and do not recurve until they reach about latitude 27.5° N. in longitude 86.5° W. (east-central Gulf of Mexico), whereas the mean paths for August, September, and October originate north of latitude 15° and recurve over Florida or the adjacent ocean, the August one on the west coast, the September one over southern Florida, and the October one at a point just touching the extreme southeast coast, but with a movement much more toward the east. It is a fact, however, that some of the most violent storms move as far west as the Texas coast before recurving, notably those of 1900 and 1915, indicating clearly that the probability of recurve and the point of recurving are governed almost entirely by the pressure distribution to the northward.

THE STORM OF AUGUST, 1915.

The meteorological history of this storm was discussed in a special bulletin issued by the Weather Bureau, and the description herewith was copied from that bulletin. Figures 1–12 (XLIII, 92–103), at the back of this REVIEW, show the paths of the storms of 1900 and 1915, and also the pressure conditions that prevailed during the passage of the storm of 1915. Charts for 8 a. m. only, are shown for the period from August 10 to 14, inclusive, while both the 8 a. m. and 8 p. m. charts are reproduced for the period from 8 a. m. August 15 to 8 p. m. August 17, inclusive.

When the storm passed inland from the Texas coast, observations became available giving for the first time the barometric pressure at the approximate center and closely adjacent points. The lowest pressure at Houston, Tex., was 28.20 inches, and it is fair to assume that the pressure at the center of the storm throughout its journey across the Gulf of Mexico was at least as low as 28.5 inches. Isobars in dotted lines have therefore been drawn on the maps on this basis, showing the passage of the storm over the Gulf of Mexico, although only a few scattered reports were available, and they for points at a distance from the center.

This storm proved to be somewhat of an exception to the rule for the pressure conditions that prevailed for a week or two previous were not such as to indicate any probability of the development of a tropical disturbance. It is true that pressure had been quite high over much of the United States and the North Atlantic Ocean during July, and relatively low over the eastern Atlantic as indicated by reports from the Azores Islands, but during the first decade of August these conditions were reversed over the Atlantic States and the western portion of the Atlantic Ocean, although not decidedly so over the ocean where the pressure was still slightly above normal. Thus, as has been said, there was nothing to indicate that conditions were favorable for the formation of a tropical storm, nor, should one form, was there anything pronounced to indicate its direction of progression, whether northwestward to the south Atlantic coast or westward to the Gulf of Mexico, the slight preponderance of pressure over the North Atlantic not having been sufficient to enable this fact to be determined.

The storm was first observed on the morning of August 10 between the Windward Islands of Barbados and Dominica, and at 9:45 a. m. on that date the first warning notice of the storm was sent to West Indian stations. At 2 p. m. similar information was sent to all Atlantic and Gulf stations of the Weather Bureau, and in addition the information was disseminated by the radio station at Arlington, Va. Nothing more definite from the scene of trouble was received during the day, except a special report at 4 p. m. from Roseau, Dominica, which showed a barometer reading of 29.46 inches, with light air from the northwest. On the morning of August 11 the disturbance was apparently near and south of the

[2] West Indian Hurricanes. Washington, 1900. (Weather Bureau Bulletin H.)
[3] Hurricanes of the West Indies. Bulletin X, Weather Bureau. 1913.
[4] Cyclonic Circulation and the Translatory Movement of West Indian Hurricanes. Washington, 1898. (Weather Bureau No. 168.)
[5] Summary of International Meteorological Observations. Washington, 1893. (Weather Bureau Bulletin A.)

island of St. Croix, at about latitude 16° N., longitude 66° W. At this time the barometer at San Juan, P. R., read 29.60 inches with a gale of 60 miles an hour from the northeast, indicating a much lower pressure to the southward, and pressure was falling more rapidly to the westward, as indicated by the observations at Santo Domingo, Santo Domingo, and Port au Prince, Haiti. The following information was then distributed over the West Indies generally and to Atlantic and Gulf ports:

Severe tropical disturbance at 8 a. m. apparently central near island of St. Croix, moving west-northwest 18 or 20 miles and hour. Will probably cross Santo Domingo and Haiti, reaching southeastern Cuba about Thursday night or Friday (Aug. 12–13).

On the morning of the 12th the storm was central a short distance south of Haiti at about latitude 17°, longitude 73°. The barometer reading at Port au Prince was 29.60 inches and the highest wind velocity was 32 miles an hour from the east. However, reports of damage over the southern portion of the Republic indicated that a severe gale must have occurred there with much lower pressure. On the same morning the barometer reading at Kingston, Jamaica, was 29.68 inches, and northerly gales were reported east of the island. The wind at Kingston was then light northwest, and pressure was also falling to the westward and northwestward, Songo (near Santiago), Cuba, reporting a barometer reading of 29.80 inches, a fall of 0.16 inch in 24 hours, with light northeast winds. Warnings were again issued at about 10 a. m. to the effect that the tropical storm was apparently central near southwest Haiti, moving a little north of west, and that it would probably reach southeast Cuba that (Thursday) night. Observations taken at 12 noon of the 12th indicated that the storm center was near the east coast of Jamaica, moving a little north of west, and advices were issued accordingly to all Gulf and Atlantic ports, and also to West Indian points that were likely to be affected.

During the night of the 12–13th the storm center passed north of the Island of Jamaica, and at 8 a. m. of the 13th a whole southeast gale was blowing at Kingston. Northeast storm warnings were then ordered at Key West and Miami, Fla., and advices issued stated that the storm would probably reach western Cuba Friday night and Saturday, and that hurricane warnings might be necessary later. All interested, and especially shipping, were advised at the same time to take every precaution necessary for safety. At this time the barometer reading at Key West was 29.92 inches, and the wind velocity 16 miles an hour from the east. Special observations received during Friday, the 13th, indicated that the storm was moving as forecast, and accordingly at 5 p. m., the warnings at Key West and Miami were changed to hurricane, and hurricane warnings were also ordered on the southwest coast of Florida as far north as Boca Grande. The warnings stated that easterly winds would increase that night possibly reaching hurricane force Saturday. All shipping and others interested were warned to take every precaution possible and vessels in port were warned to remain there.

On the morning of the 14th the storm was apparently central near the Isle of Pines, Cuba, with undiminished intensity and moving in a direction a little north of west. Advisory warnings on that morning, which were sent to all interested, stated that the storm would probably pass into the Gulf of Mexico that (Saturday) night. During Friday night the maximum wind velocity at Habana was 56 miles an hour from the east. It was apparent that during Sunday the storm center would probably reach the north-central Gulf of Mexico, and Gulf shipping was advised to take every precaution. At 5 p. m., Saturday, the 14th, hurricane warnings were continued from Key West to Boca Grande, but were lowered at Miami, as it was apparent that there was no longer any danger of winds of storm force at that station. As the next day would be Sunday, the officials in charge at Weather Bureau stations were ordered to make arrangements for Sunday telegraph service in their districts in order that any warnings that might be necessary could be received and distributed properly. On the morning of the 15th the storm was apparently central in the south-central Gulf of Mexico moving in a more northwesterly direction than before. The barometer at all Gulf stations was falling, and northeast storm warnings were therefore ordered on the Gulf coast from Apalachicola, Fla., to New Orleans, La. All Gulf stations, both regular and display stations, were notified accordingly, with warnings that all interested should take every precaution for safety, and that all vessels should remain in port. The special observations received during Sunday, the 15th, indicated the necessity of hurricane warnings on the west coast, and at 5 p. m. the northeast warning at New Orleans was changed to hurricane, and hurricane warnings were also ordered at all display stations westward as far as Brownsville, Tex. A radio report taken at 2 p. m. on the S. S. *Antilles*, at latitude 27°, longitude 86°, showed a barometer reading of 29.54 inches with wind velocity of 74 miles an hour from the east, and another radio report taken at 8 p. m. on the same date, at about latitude 26.5°, longitude 87.5°, showed a barometer of 29.48 inches, with wind velocity of 64 miles an hour from the east. On Monday morning, August 16, the storm center was apparently approaching the east Texas coast and the warnings from Mobile to Apalachicola were changed from northeast to southeast. At this time the barometer at Galveston read 29.62 inches with maximum wind velocity of 34 miles an hour from the northeast. The conditions continued to intensify, and by noon the barometer at Galveston had fallen to 29.48 inches with maximum wind velocity of 56 miles an hour from the northeast. The tide was rising slowly and the sea was excessively rough. At 5 p. m. the hurricane warnings were ordered continued from Sabine, Tex., to Brownsville, Tex., and the warnings at New Orleans and Morgan City, La., changed from hurricane to storm southeast, as it was apparent that the winds at these places could no longer increase, the maximum wind velocity at Burrwood, La., at the mouth of the Mississippi River, being only 48 miles an hour from the east. At 8 p. m. Monday, August 16, the barometer at Galveston read 29.10 inches with maximum wind velocity of 72 miles an hour from the northeast, and heavy rain was falling. The storm passed into the interior during the night of August 16–17, and at 2:45 a. m. Tuesday, August 17, the barometer at Galveston read 28.63 inches, with maximum wind velocity of 93 miles an hour from the east at 2:37 a. m. At 5:30 a. m. of the 17th the barometer at Houston read 28.20 inches, with a maximum wind velocity of 80 miles an hour (estimated) from the northeast.

Hourly barometer readings were also made by E. F. Roeller at Velasco, Tex., about 40 miles southwest of Galveston and about 14 miles southwest of San Luis Pass, where the storm center first reached the coast. The curve plotted from his readings forms figure 13. It shows that the lowest pressure, 28.06 inches, occurred at 1 a. m. August 17, at which time the wind backed from

north to northwest. The table following gives the pressure and wind direction at frequent intervals during the height of the storm at Velasco:

TABLE 1.—*Barometer readings by E. F. Roeller at Velasco, Tex., during August 16 and 17, 1915.*

[Correction of +0.08 inch to be applied.]

Date and hour. [90th mer. time.]	Barometer reading.	Wind.	Date and hour. [90th mer. time.]	Barometer reading.	Wind.
Aug. 16, 1915.	*Inches.*		*Aug. 16, 1915*—Contd.	*Inches.*	
1:20 p. m.	29.40	ne.	10:00 p. m.	28.66	n.
2:00 p. m.	29.38	ne.	10:20 p. m.	28.60	n.
2:20 p. m.	29.36	ne.	10:30 p. m.	28.56	n.
2:45 p. m.	29.34	ne.	10:50 p. m.	28.50	n.
3:15 p. m.	29.30	ne.	11:10 p. m.	28.48	n.
3:30 p. m.	29.28	ne.	11:30 p. m.	28.40	n.
3:45 p. m.	29.24	ne.	11:45 p. m.	28.34	n.
4:15 p. m.	29.22	ne.	12:00 p. m.	28.28	n.
4:30 p. m.	29.20	n.	12:15 a. m.	28.24	n.
5:00 p. m.	29.18	n.	12:25 a. m.	28.18	n.
5:30 p. m.	29.14	n.	1:00 a. m.	28.14	nw.
6:10 p. m.	29.12	n.	1:30 a. m.	28.18	nw.
6:40 p. m.	29.08	n.	1:50 a. m.	28.30	nw.
7:00 p. m.	29.06	n.	2:15 a. m.	28.40	nw.
7:20 p. m.	29.02	n.	2:30 a. m.	28.45	w.
7:45 p. m.	28.98	n.	2:45 a. m.	28.50	w.
8:10 p. m.	28.94	n.	3:15 a. m.	28.60	w.
8:50 p. m.	28.90	n.	3:40 a. m.	28.70	w.
9:15 p. m.	28.82	n.	7:15 a. m.	29.20	sw.
9:25 p. m.	28.80	n.	12:40 p. m.	29.40	sw.
9:40 p. m.	28.74	n.			

This reading of 28.06 inches was not by any means unprecedented, as numerous readings below 28 inches have been recorded during severe storms in different parts of the world. During more recent years probably the lowest recorded pressure was 27.24 inches. This observation was taken on the schooner *Ponape*, lying at anchor at Wlea, West Caroline Islands, at 10 a. m. March 29, 1907, and was noted by Algué in the Monthly Bulletin of the Philippine Weather Bureau for March, 1907.

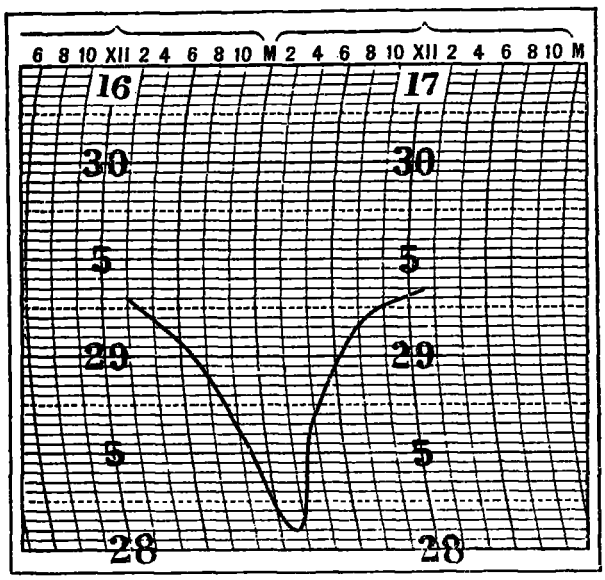


FIG. 13.—Plot of corrected aneroid readings (inches) by E. F. Roeller at Velasco, Tex. August 16–17, 1915.

At 8 a. m. Tuesday, August 17, the barometer at Galveston read 29.12 inches, with the wind blowing 52 miles an hour from the northeast, while at Houston the reading was 28.72 inches, with a wind of 80 miles an hour (estimated) from the southeast. Torrential rains had fallen at both places and were extending into the interior of east Texas. The storm then recurved to the northward, with high winds over the interior of east Texas, reaching a maximum of 60 miles an hour from the north at San Antonio during the day. There was no occasion for further warnings, and those that were still displayed were allowed to expire at 5 p. m. Tuesday, August 17. On the morning of August 18 the storm was central over the northern portion of east Texas, with a barometer reading of 29.50 inches at Fort Worth and Dallas, with northeast gales of 44 to 48 miles an hour and with heavy rains. Warnings of high winds for the interior of east Texas had

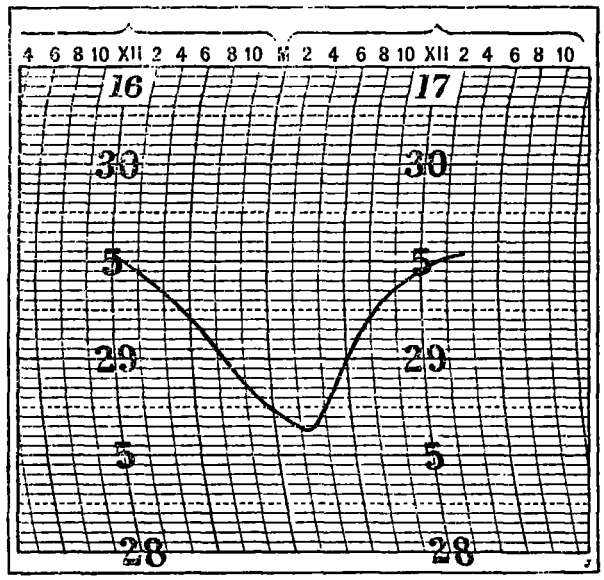


FIG. 14.—Barogram (inches) at Galveston, Tex., noon August 16 to 3 p. m. August 17, 1915.

been issued on the afternoon of the 17th. During the next 24 hours the storm moved very slowly to extreme northeast Texas with somewhat diminished intensity, but with heavy rains continuing in that vicinity and extending into Arkansas. The storm was now moving northeastward, and on the morning of the 20th was central over southeast Missouri with somewhat increased intensity, and heavy rains had fallen in southern and eastern Missouri, the lower Ohio Valley, and west Tennessee, and northeasterly gales prevailed at St. Louis. During the next 24 hours the storm moved slowly to southern Indiana, again with diminishing intensity, but with general rains and some high winds to the southeastward. It then continued its northeastward movement with steadily diminishing intensity, but with general and, in many places, heavy rains, and on the morning of August 24 was passing out into the Gulf of St. Lawrence, with a barometer reading of 29.80 inches at Father Point.

The hourly barometric pressures at Galveston and Houston during the passage of the storm near those stations are shown in the barograms, figures 14 and 15. It will be seen that at Galveston the pressure fall from noon to 6 p. m. on Monday, August 16, was uniform at the rate of 0.06 inch an hour. From 6 p. m. to 10 p. m. the fall was a little more rapid, ranging from 0.08 to 0.12 inch an hour, and the pressure fell below 29 inches for the first time shortly after 8 p. m. From 10 p. m., when the reduced barometer read 28.82 inches, until 2:45 a. m., August 17, at which time the lowest reading of 28.63 inches was recorded, the rate of fall was less than before, averaging a little less than 0.04 inch an hour. From 2:45 a. m. until 9 a. m., August 17, there was a recovery at a much more rapid rate, about 0.11 inch an hour, followed by a much slower rate of rise thereafter.

At Houston the barometer fell at the rate of about 0.04 inch an hour from noon until 8 p. m., August 16, and much more rapidly thereafter, falling below 29 inches at about 12:30 a. m., August 17, about four and one-half hours later than at Galveston. The lowest reading of 28.20 inches, or 0.43 inch lower than at Galveston, was reached at 5:25 a. m., August 17, two hours and forty minutes later than at Galveston. From 8 p. m., August 16, to 5:25 a. m., August 17, the total fall in pressure was 1.18 inches, an average of about 0.125 inch an hour. From 3 a. m. to 5 a. m., August 17, the fall was 0.47 inch, an average of 0.235 inch an hour, while the greatest fall during a single hour was 0.30 inch from 4 a. m. to 5 a. m., August 17. At Galveston the greatest fall in any one hour, 9 p. m. to 10 p. m., August 16, was only 0.12 inch. These figures show that the actual storm center passed much closer to Houston than to Galveston, and, according to the wind directions (NE., E., SE., and S.), a little to the southward and westward of both stations.

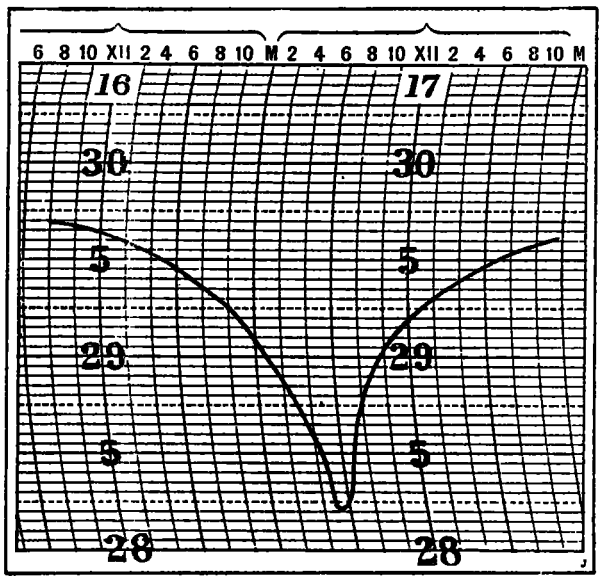


FIG. 15.—Barogram (inches) at Houston, Tex., 8 a. m. August 16 to 12 p. m. August 17, 1915.

As nearly as can be determined the storm center reached the coast of Texas near San Luis Pass, at the end of West Bay, about 26 miles southwest of Galveston, at about 1 a. m., September 17, shortly after which its slow recurve to the northward and northeastward began. The extreme western point of the path was reached between 2:20 and 2:40 a. m., very near and presumably a little to the westward of Sandy Point, Tex. It was next definitely located at about 4:50 a. m. southwest of and very close to Houston, Tex., with a movement slightly east of north.

These deductions are based upon special reports received, mainly, after the passage of the storm, and the center is assumed to have been where the lull, or "calm," that accompanies the shift in wind direction occurred as the storm center passed. At a point about 5 miles northeast of Sandy Point the calm lasted from 2:20 until 2:40 a. m. The time consumed by the storm center in traveling from the coast to Houston, a distance of about 60 miles along the curved path, was very nearly four hours, making the average rate of progression 15 miles an hour. As the calm near Sandy Point lasted about twenty minutes, or one-third of an hour, it may safely be assumed that the diameter of the storm center was one-third of 15, or 5 miles. Some confirmation of this is found in the official report from Houston in which was stated the fact that in Houston the broken and uprooted trees pointed toward the southwest, while 6 miles southwest of Houston they pointed to the north and northward, indicating violent winds in opposite directions within a distance of 6 miles, from which it may be inferred that the storm center could not have been more than 6 miles in diameter.

The storm center evidently passed over Cape San Antonio, Cuba, about 2:30 p. m. August 14, as at that time a calm prevailed, continuing with heat and mist for about one-half hour. The lowest barometer at the Isle of Pines, Cuba, occurred at 3 a. m. August 14, so that the rate of travel of the storm center between that place and Cape San Antonio was about 13 miles an hour. As it occupied one-half hour in passing over Cape San Antonio, the diameter of the center was apparently about 6½ miles, a very close agreement with the results obtained between San Luis Pass and Houston, Tex.

The following extract regarding the conditions prevailing over the Gulf of Mexico was made from the report of Mr. W. P. Stewart, official in charge of the local office of the Weather Bureau at Galveston:

The recording tide gages of the United States Engineers at Fort Point and of the United States Coast Survey on the wharf at Twentieth Street were carried away by the storm together with their records. There is, therefore, no official record of the tide. A measurement by the United States Engineers at Twentieth and Strand makes the highest point reached 11.965 feet above mean low tide. It appears to be the universal opinion that the water was somewhat higher than in 1900. At 2119 Post office, the highest water in both storms is chiseled on the wall and the record of the recent storm is 3.5 inches higher than that of 1900.[6]

At its highest the water in the retail business district was approximately 5 feet above the street level, the streets being about 6.5 feet above mean low tide. At the American National Insurance Co.'s building it was 5 feet 6.5 inches; at 2110 Avenue E, 4 feet 9 inches; at Tussup Grocery Co.'s store, Twenty-second and Post office, 4 feet 11.5 inches; at Twenty-second and Mechanic, 5 feet 2 inches; at Union Depot, 6 feet. In that part of the town where grade has been raised it was of course not so deep. At Twenty-second and Q it was 2 feet 7 inches; at the county courthouse, 4 feet 11 inches above the street level at the curb.

During the morning of August 15, there was a light southeast swell on the Gulf coming in against a light northeasterly wind. The tide was slightly above normal and it was noticed that it did not fall when it should have done so. During the afternoon it rose slowly and the swells noticeably increased. During the early hours of the 16th the tide rose about 0.3 foot an hour and by daybreak the sea was very rough. At 6:30 a. m. the tide was 4.1 feet and about stationary, but it rose slowly after that time and the sea became increasingly rough. During the afternoon of the 16th and for 36 hours thereafter it was excessively rough. The water began to back in from sewers on down-town streets about noon. At first it rose very slowly and it was 6 p. m. before the streets in the business section were all covered. After that time it rose more rapidly and by 9 p. m. the water was 3 feet deep at Twenty-third and Post office. During the late afternoon the street-car and electric-light services suspended operations and during the early part of the night the gas and water services failed. The tide was highest about the climax of the storm, a little before 3 a. m., August 17. At daybreak it had subsided about 2 feet and the water was again 3 feet deep on the street at Twenty-third and Post office. The tide fell slowly and there was water on some streets until the morning of the 18th.

A curious, although entirely natural, sequence of the storm was the high temperature that prevailed along the southern coast of Texas, beginning with August 15 when the winds first shifted to landward, the fall in temper-

[6] While the water was 3.5 inches higher at the post office in Galveston than in 1900, the highest tide of 11.965 feet does not appear to have been as high as that of the storm of 1900, assuming that the statements of Dr. I. M. Cline regarding the latter are correct. Dr. Cline said (MONTHLY WEATHER REVIEW, Sept. 1900, 28: 373):

"* * * The water had now reached a stage 10 feet above the ground at Rosenberg Avenue (Twenty-fifth Street) and Q Street, where my residence stood. The ground was 5.2 feet elevation, which made the tide 15.2 feet. The tide rose the next hour, between 7:30 and 8:30 p. m., nearly 5 feet additional, making a total tide in that locality of about 20 feet. These observations were carefully taken and represent to within a few tenths of a foot the true conditions. Other personal observations in my vicinity confirm these estimates. The tide, however, on the bay or north side of the city did not obtain a height of more than 15 feet. It is possible that there was 5 feet of backwater on the Gulf side as a result of débris accumulating 4 to 6 blocks inland."

ature that usually follows the passage of a storm center over or near a given locality having been entirely absent. In this instance the winds blowing from a warm land area brought with them the high temperatures that prevailed over the interior districts, and the condition persisted until the wind again blew from the water surface to the southeastward. The following data show the conditions at Corpus Christi and Brownsville, Tex., from August 15 to 20, inclusive:

Date.	Maximum temperature during day.		Wind direction at 8 p. m.	
	Corpus Christi.	Brownsville.	Corpus Christi.	Brownsville.
	°F.	°F.		
Aug. 15	91	92	ne.	n.
16	94	97	nw.	nw.
17	97	a 104	nw.	s.
18	a 100	a 104	b se.	se.
19	98	100	s.	s.
20	90	99	se.	s.

a Highest temperatures of record. b Had been south during day.

CASUALTIES.

The casualties resulting from the storm were of minor character east of Santo Domingo and Haiti and were confined to small shipping. At Fort de France, Martinique, the docks were flooded and merchandise destroyed, while at some of the other islands of the Lesser Antillos there was some damage to small shipping. Over the southwestern portion of Haiti real disaster to crops, etc., was reported, but, so far as is known, without loss of life. Over the Island of Jamaica heavy gales were reported, and the banana crop was said to have been damaged to the extent of several millions of dollars. There were no serious disasters to shipping in the Caribbean Sea reported, and to this fortunate condition the warnings of the Weather Bureau doubtless contributed in great measure.

Over extreme western Cuba, which was in the direct path of the storm, the damage was much more serious, and at Cape San Antonio, on the extreme western end of the island, not a house was left standing. The radio station, the steel tower, and the lighthouse were blown down, and the entire meteorological equipment of the Weather Bureau destroyed. Fourteen lives were lost. The schooner *Roncador* was totally wrecked, but without loss of life, and the schooner *Explorer* was dismantled.

There were no serious disasters in the east Gulf of Mexico, although several disabled vessels came into or were brought into Key West. There was only a moderate gale at Key West, but at Sand Key, 8 miles to the southwestward, there was a 60-mile southeast gale.

The greatest marine disaster was the loss on August 13, probably in the Yucatan Channel, of the American steamship *Marowijne*, of the United Fruit Co., from Belize, British Honduras. Notwithstanding the fact that the steamer was equipped with radio apparatus nothing was heard from her and she must have been lost, together with her passengers and crew, numbering in all 96 persons. The vessel was valued at $400,000.

The schooner *Lydia M. Deering*, from Sabine, Tex., for Boston, was lost several miles south of Mobile, and the captain and two members of the crew perished. The schooner *Dora Allison*, from Progreso, Mexico, for Mobile, was wrecked in the Gulf, but her crew was saved. The fishing smack *Nettie Franklin*, of Pensacola, was wrecked in the northwest Gulf and two of her crew were lost.

The losses on the Louisiana and Texas coasts and in the interior of east Texas were such as might have been expected from a great storm.

Over southern Louisiana there was no loss of life, while the property loss probably did not exceed $1,000,000. It was confined mainly to the rice crop and to live stock in the marshes.

The greatest loss of life and property occurred in the vicinity of Galveston, and from thence northward and westward for a considerable distance. The total loss of life was 275, to which the city of Galveston contributed 11; Galveston Island, 42; and the dredges *Houston* and *San Bernard* and the tug *Helen Henderson*, 69. One hundred and two persons were reported as missing, but it is probable that many of these were later accounted for. We quote again from the report of Mr. Stewart:

Of the damage resulting from the direct force of the wind probably the sinking, wrecking, or grounding of vessels of all sizes caused the greatest monetary loss. There are still (August 27) 11 large vessels aground in this immediate vicinity, and several hundred vessels of all sizes were wrecked on the east Texas and west Louisiana coasts. In addition to the wrecking of vessels and the destruction of wharves and sheds along the harbor front, there was an enormous amount of comparatively minor damage due to the direct force of the wind. Windows were broken, and trees, outbuildings, and fences blown down. Of the ornamental, or shade trees, the oaks suffered the most and the palms the least. The leaves on all deciduous trees are withered and dry since the storm, and are falling. The loss from breakage of plate-glass windows in the business district was considerable, as was the loss from damage to roofs, windows, and chimneys in the residence districts.

A large part of the property damage in this storm resulted, not from the direct force of the wind, but from the high tide which flooded the business district to a depth of from 5 to 6 feet and damaged stocks of goods in both the wholesale and retail districts. Great property loss was occasioned by washing of sand from under buildings, causing their overturning or collapse. The seawall which protects the city on the east and south has a height above mean low tide of 17 feet. Reliable observers say that when the waves receded, leaving the sea momentarily calm outside the wall, the water stood about 20 inches from the top. Then, when the larger waves came, an enormous amount of water was projected over the wall. This water washed the sand from under the brick pavement of the seawall boulevard, practically destroying it for 20 blocks. The sand filling or "made ground" inside the seawall boulevard sloped upward toward the center of town. This sand fill had a width of 300 to 400 feet, a depth of 17 to 23 feet and a length of about 2 miles, and was designed to cause the flood waters to flow back into the Gulf. However, it was covered with soil or sod only in a few small patches and wherever not so protected it was washed by the incoming waters back into the town and from under the numerous dwellings that covered it. In this way approximately 200 residences were undermined and more or less seriously damaged. Some were entirely destroyed and nearly all were rendered unfit for habitation. Isolated cases of undermining of houses also occurred in several sections remote from the Gulf front. The sand washed away from near the beach was left farther inland. Some of the street pavements and most of the lawns in the southeastern part of town were covered with sand to a depth of from 2 to 5 feet. About six blocks of single track street railway was undermined and destroyed.

At Fort Crockett the damage is estimated at over half a million dollars. The sand-protected forts were nearly demolished and the sand filling of the military reservation was badly washed. The loss of military equipment was also considerable.

Of the 250 homes on Galveston Island outside the protection of the seawall probably not over 10 per cent are left standing. That there were not more fatalities in that section was due solely to the warnings of the Weather Bureau.

Serious loss resulted from several fires that broke out during the night of the 16th–17th. Along the Gulf front all the structures outside the seawall were destroyed by the storm. The causeway that connected Galveston Island with the mainland was badly damaged. The central part of the structure which consisted of concrete arches did not suffer severely, nor were the dirt and oyster shell approaches at either end seriously damaged, but those portions connecting the central arched section with the shore on either side—each nearly a mile in length—were demolished down to the solid concrete structure that stands slightly above mean tide. It has been estimated that the cost of repairing or reconstructing the causeway will be approximately $500,000. The practical destruction of the causeway was accompanied by the loss of portions of the water main which brought the city water supply from artesian wells at Alta Loma. There was no city water

FIG. 16.—Galveston hurricane of August 16–17, 1915. Wrecked Casino and Columbo Café at head of Twenty-third street. Note three granite blocks, each weighing 20 tons, driven across the street from the balustrade of the sea wall by force of waves.

FIG. 17.—Galveston hurricane of August 16–17, 1915. North end of the causeway looking toward Virginia Point Railroad, showing the demolished embankment fill; on the right is the dredge *Houston* thrown upon the causeway.

[To face p. 410.]

FIG. 18.—Galveston hurricane of August 16–17, 1915. View of the break in the embankment fill portion of the causeway, with wrecked interurban cars in middle ground. The arched-bridge portion of the causeway, 1,700 feet, remains standing.

FIG. 19.—Interurban track at Virginia Point, looking north. The track and overhead wires were destroyed for a distance of about 3 miles from this point.

[To face p. 411.]

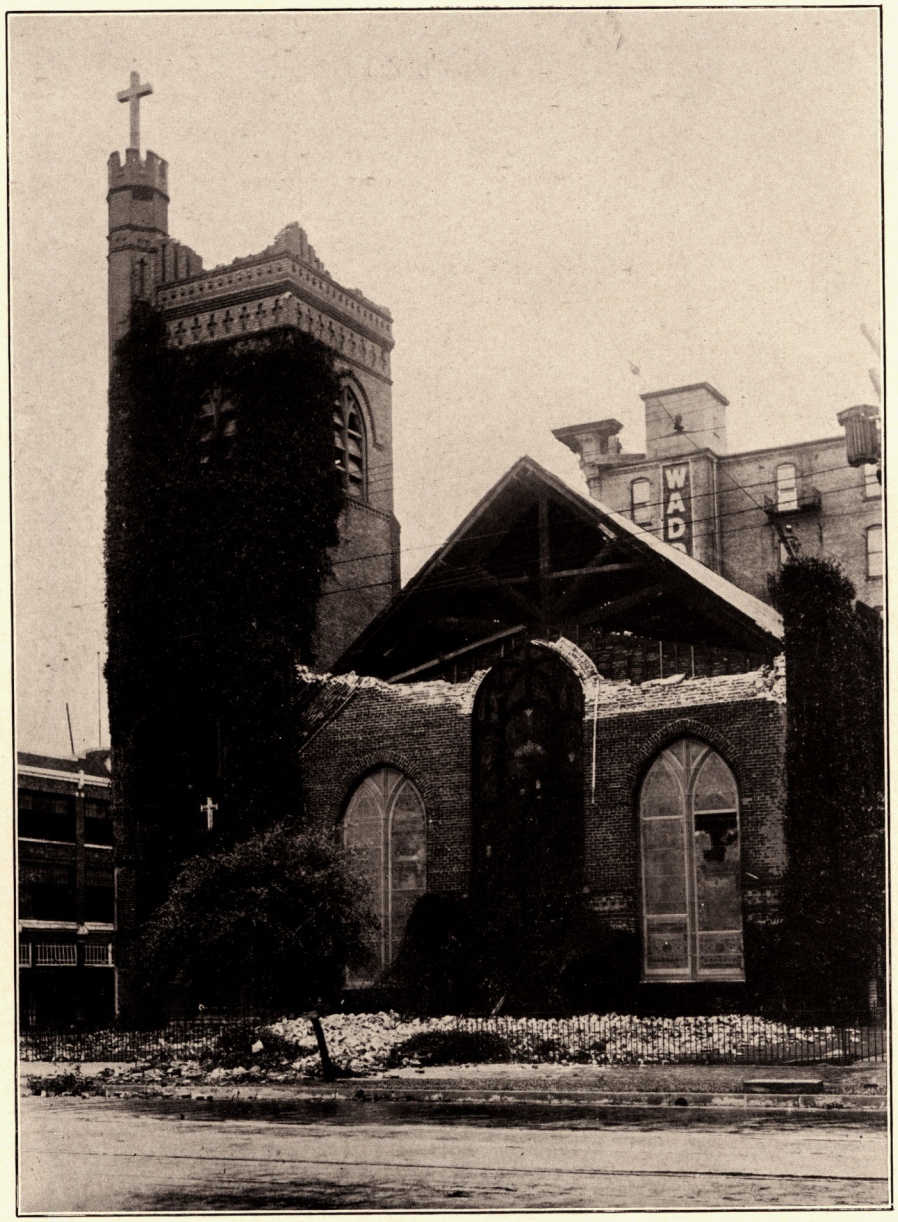


FIG. 20.—Damage to First Christ Church, Houston, Tex., August 16–17, 1915. (Howerton, photographer.)

[To face p. 411.]

FIG. 21.—Damage to the Airdome, Houston, Tex., August 16–17, 1915. (Howerton, photographer.)

from the night of the 16th until the morning of the 26th of August. There was little actual suffering on that account, however, as water for cooking and drinking purposes was obtained from cisterns and several artesian wells in the city.

Post-office inspectors report the destruction of the post offices at Chocolate Bayou, Glen, Kemah, Lynchburg, Quintana, Tomball, Wallisville, and Winfree, Tex., with all contents.

The greater portion of the Marconi wireless station fell across and wrecked the building in which the station was located. The only telegraph service in or out of Galveston from the evening of the 16th of August until the morning of the 21st was by radio from the U. S. Army transport *Buford*.

It has been estimated that the damage from this storm to crops, buildings, railroads, shipping, live stock, and other property will aggregate close to $50,000,000, but these figures are probably much too large. Of the total amount approximately $6,000,000 occurred at Galveston.

In the city of Houston the damage amounted to about $1,000,000, mainly to buildings, railroads, telegraph and telephone lines, and nearly every building shared in the damage. Crops in fully one-half the State of Texas suffered severely. Nearly all open cotton was blown away, and much cotton, late corn and rice was flattened by the wind and rain.

Beyond the State of Texas there was also considerable damage by high winds as far as the lower Ohio Valley, particularly over eastern Missouri, but much greater damage was caused by the severe floods resulting from the torrential rains that extended from Texas northeastward to New York. These floods seriously injured the crops in many localities, while in many others where there were no floods, the heavy rains beat down the standing crops

COMPARISON WITH THE STORM OF 1900.

Figure 1 (XLIII–92) shows the paths of the storms of 1900 and 1915. An inspection of these paths discloses the fact that the total time occupied from the first to the last appearance of both storms within the field of observation was exactly 14 days, and that the storm of 1900 moved with a slower velocity of progression before reaching its recurve than after, whereas in the storm of 1915 the reverse was true. The two paths are very similar in many respects, although that of 1915 lay a little to the southward of that of 1900 until the St. Lawrence Valley was reached. In previous published reports on the storm of 1900 the storm path shows a strong deflection toward the southwest Florida coast, but reports received from vessels and other sources after those publications indicated the fact that this deflection to the right was not so strong as has been supposed, and the track as here charted is thought to represent more nearly the true conditions. It was carefully plotted from all available observations. As to the comparative intensities of the two storms, it is perhaps idle to speculate. The wind velocities were not greatly different, and the effects of the two storms were much the same, except as modified by artificial conditions in the vicinity of Galveston. The barometer reading of 28.48 inches at Galveston in 1900 was 0.15 inch lower than the lowest reading recorded in 1915, whereas the lowest reading of 28.20 inches at Houston in 1915 was 0.28 inch lower than the lowest barometer reported in Galveston in 1900. Unfortunately there are no records from Houston for the year 1900, and a precise comparison can not be made.

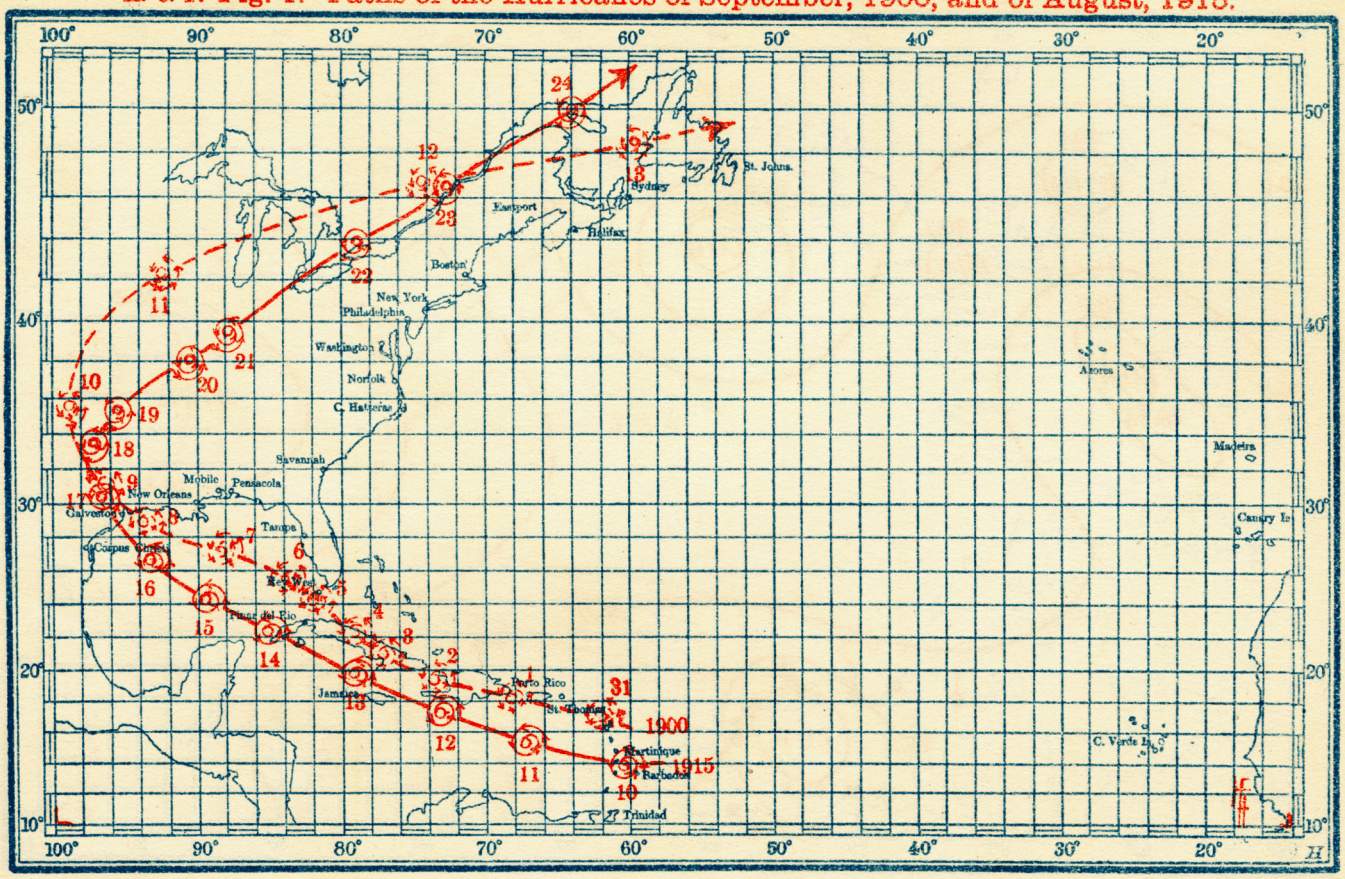
THE WORK OF THE WEATHER BUREAU IN CONNECTION WITH THE STORM.

If one may judge from press reports and letters received at the Weather Bureau, the warnings issued were the most complete and successful ever issued by the bureau for a tropical storm. Granting this to be true, it must not be assumed that the thoroughness and efficacy of the warnings were alone due to the work of any particular individual. In very large measure the success in forecasting the path and rate of the movement of the storm was rendered possible by the splendid radio service which has become a valuable adjunct of Weather Bureau forecast work since the last severe tropical storm. While it is true that no reports were received from the immediate vicinity of the storm center, probably because the warnings kept the vessels away, those that were received after the storm passed over extreme western Cuba were sufficiently close to the eastward to afford extremely valuable assistance to the forecaster, while the almost total absence of important marine disasters bears abundant testimony to the efficiency of the warning service by means of the radio distribution. There were no useless warnings. The storm did not reach any locality that had not previously had ample warning, and no warnings were issued for any locality that the storm did not reach.

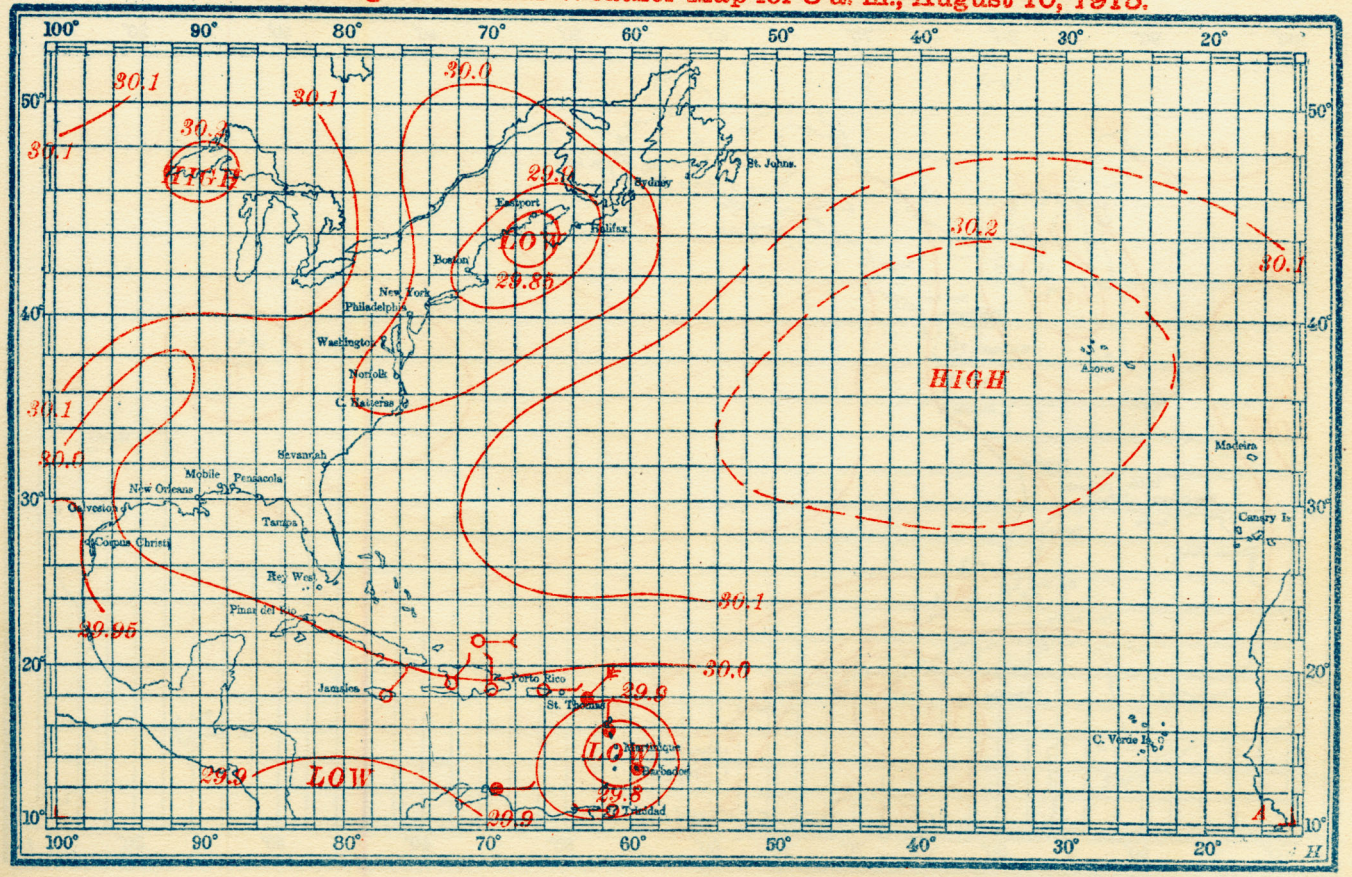
However, the splendid efficiency of the radio service can not and does not detract from the equally efficient work performed by the Weather Bureau stations along the West Indian and Gulf coasts. The distribution of the warnings was as widespread and complete as human energy could make them, and this service undoubtedly saved many lives and a considerable amount of property. Along the Louisiana coast the cordial and effective cooperation of the telegraph and telephone services and of private individuals enabled the official in charge of the local office of the Weather Bureau at New Orleans to make a wonderful distribution of the warnings, while the official in charge at Galveston and the storm warning displayman at Seabrook, Tex., by supplementing the official warnings by personal service to individuals saved many hundreds of lives. It was fortunate also for all concerned that during the first four days of the storm its center was sufficiently close to the stations of observation to enable the forecaster to indicate its velocity of movement with much greater precision than would have been possible had the storm center been at a considerable distance from land. This is an additional reason for the establishment and operation of many more stations of observation in West Indian waters, especially in the vicinity of Panama, if the Weather Bureau is to be able in the future to forecast the approach, progression, and intensity of West Indian hurricanes for the benefit of the commerce and the military establishment of the United States. This same thought should also be extended so as to comprise a more enlarged radio service in West Indian waters. The radio service now conducted by the Weather Bureau in cooperation with the Navy Department, and commercial organizations is extremely effective and valuable, but it is confined entirely to the waters of the western Atlantic, the western Caribbean, and the Gulf of Mexico. Reports are rarely received from the eastern Caribbean, but with the extension of the commercial activities of the United States in the days to come it is to be hoped that this field will be covered as carefully and as fully as are the adjacent waters.

It is a pleasure also to make grateful acknowledgment here of the services rendered by Señor Luis G. y Carbonell, chief of the meteorological service at Habana, Cuba, while the storm was passing through the Caribbean Sea. Señor Carbonell responded promptly to every request for special observations from various points in Cuba, often at inconvenient hours, and the data were of great assistance to the forecaster.

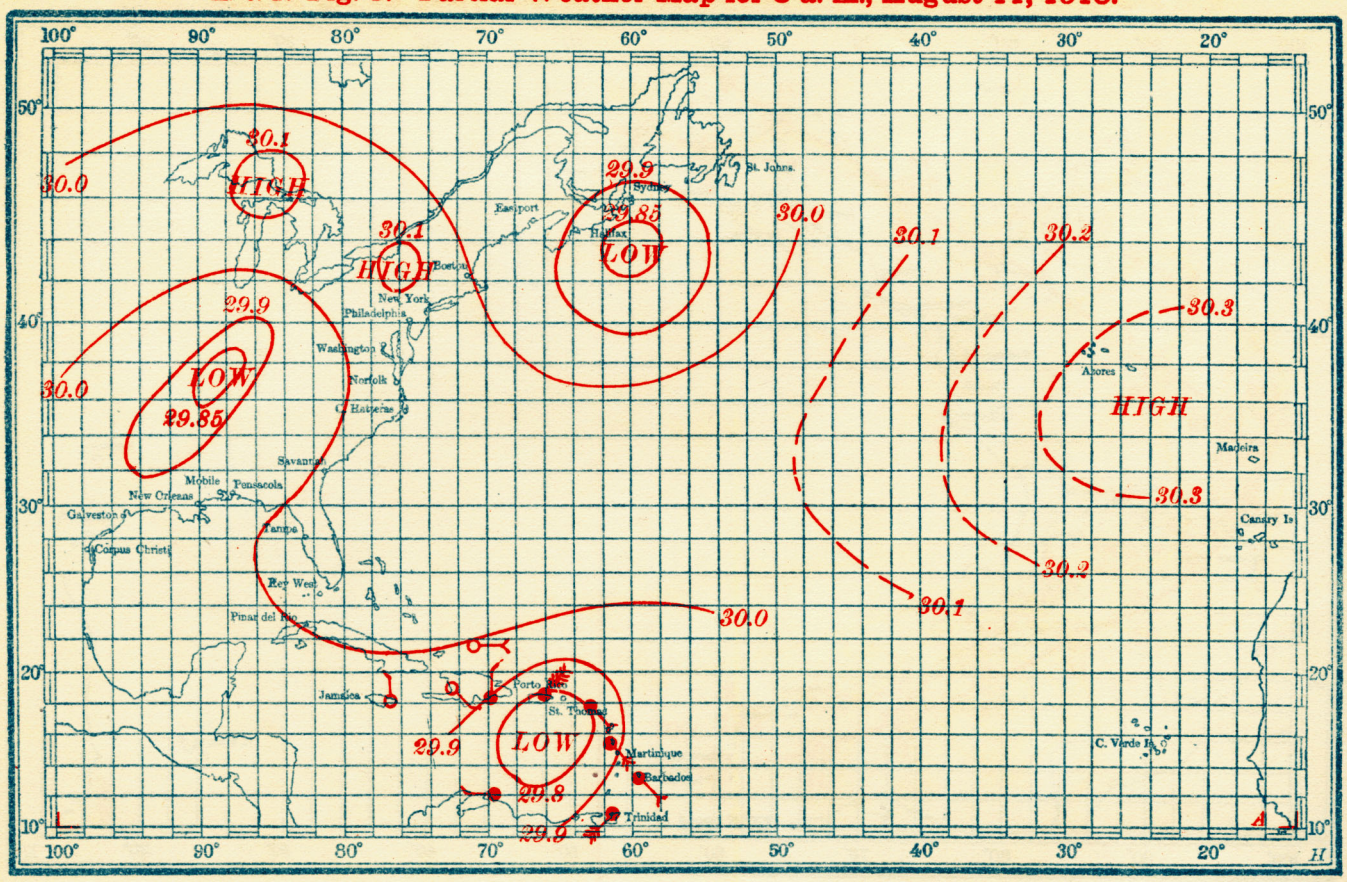
H. C. F. Fig. 1. Paths of the Hurricanes of September, 1900, and of August, 1915.



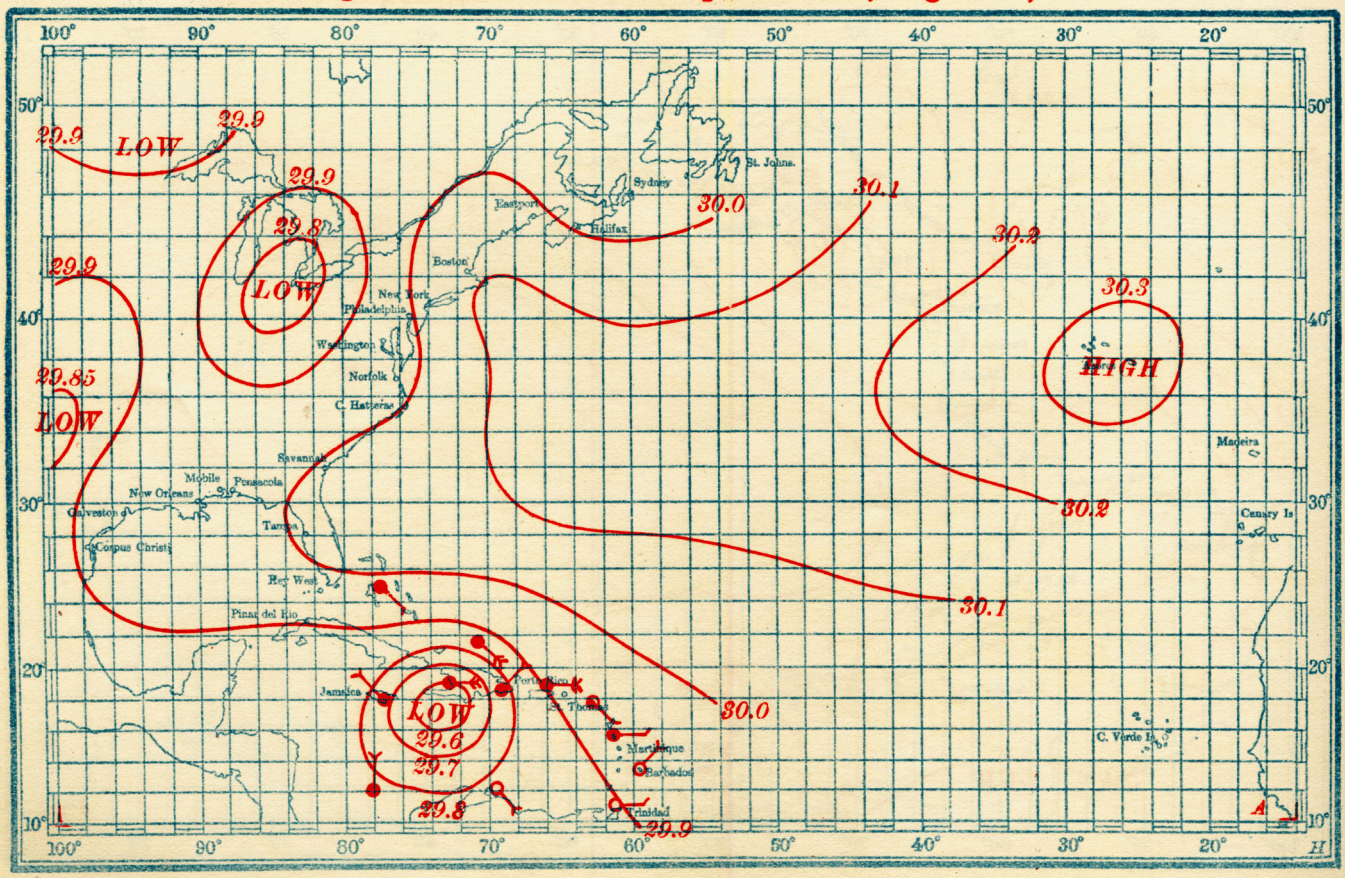
H. C. F. Fig. 2. Partial Weather Map for 8 a. m., August 10, 1915.



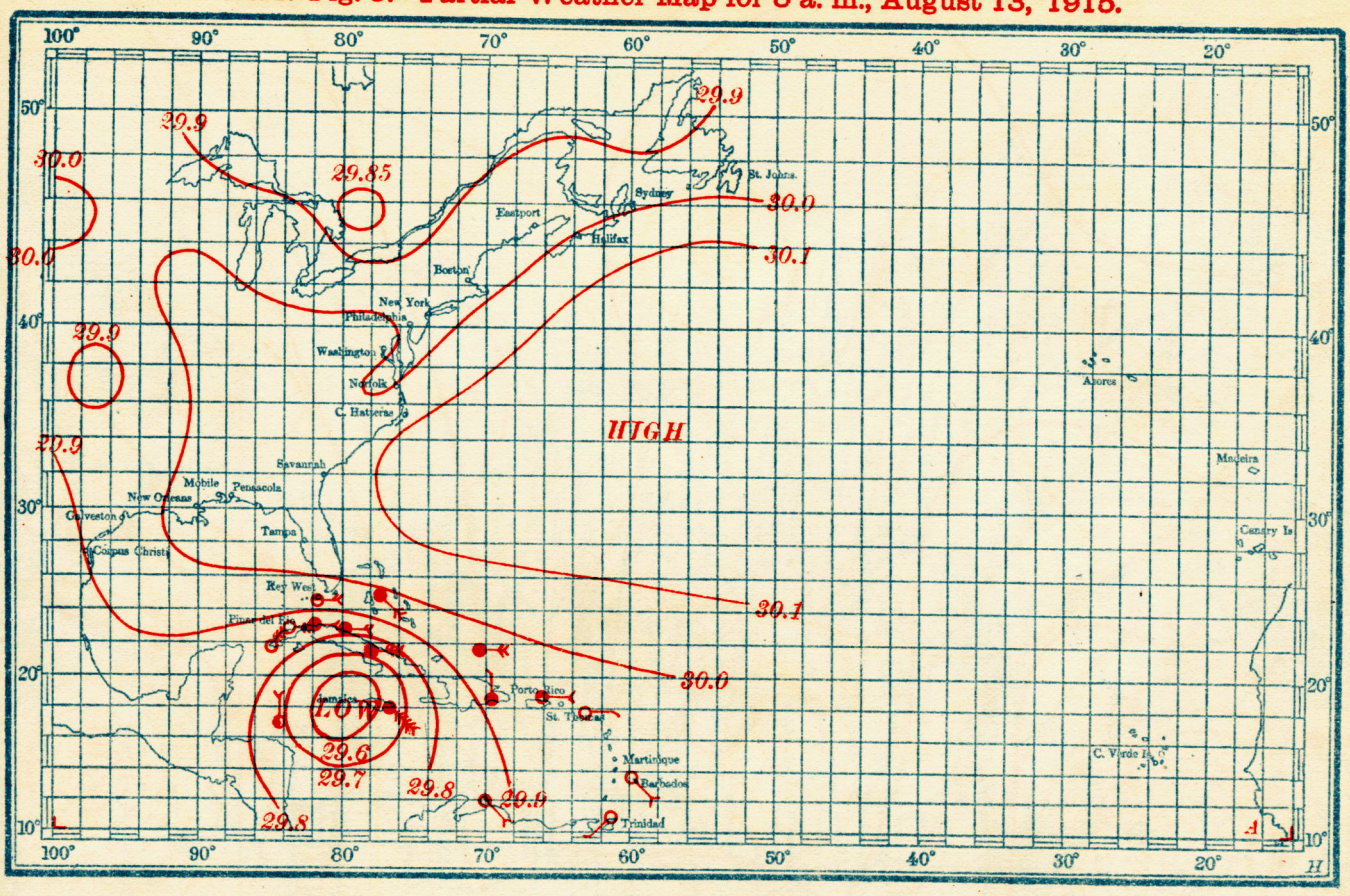
H. C. F. Fig. 3. Partial Weather Map for 8 a. m., August 11, 1915.



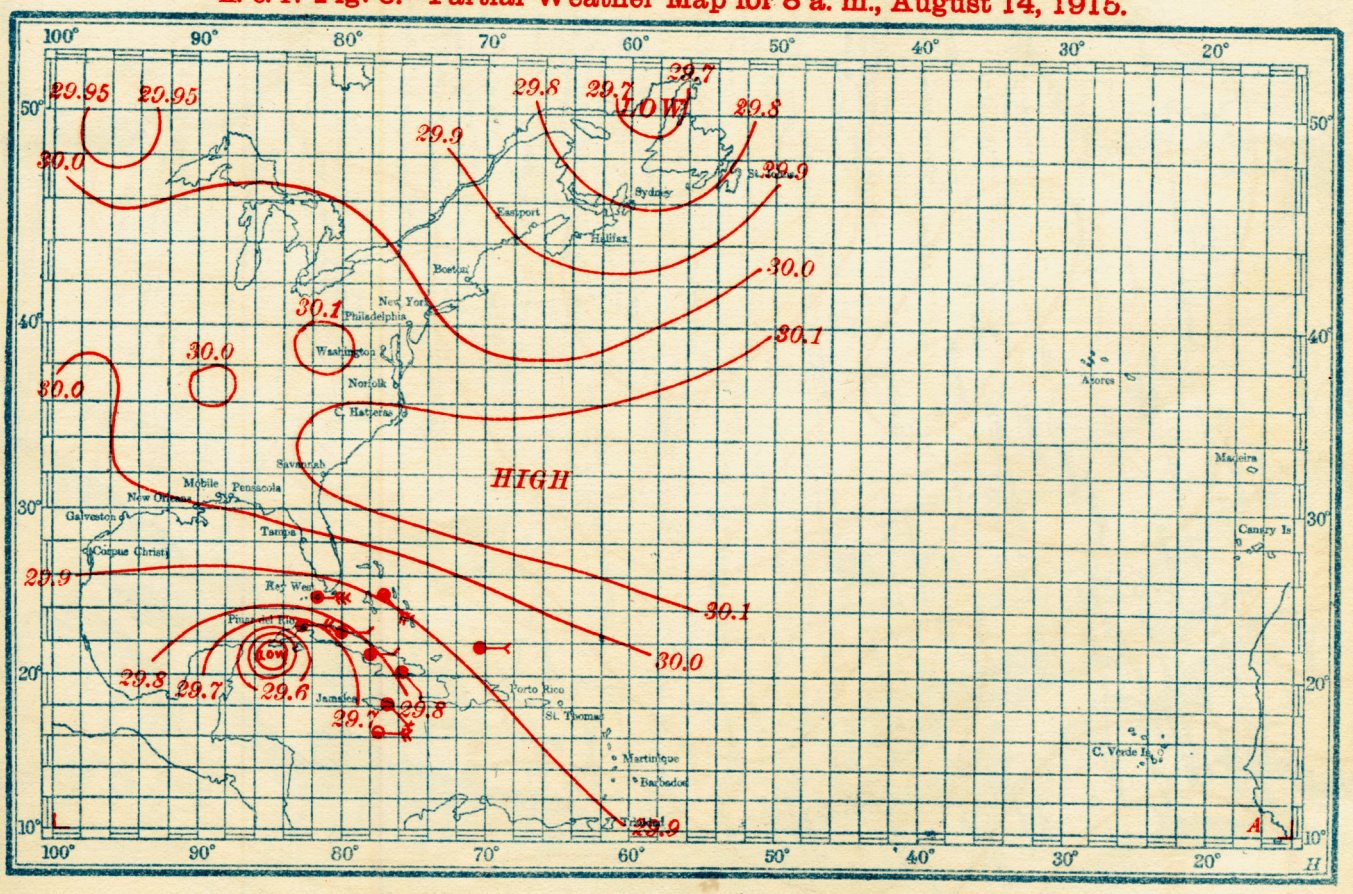
H. C. F. Fig. 4. Partial Weather Map for 8 a. m., August 12, 1915.



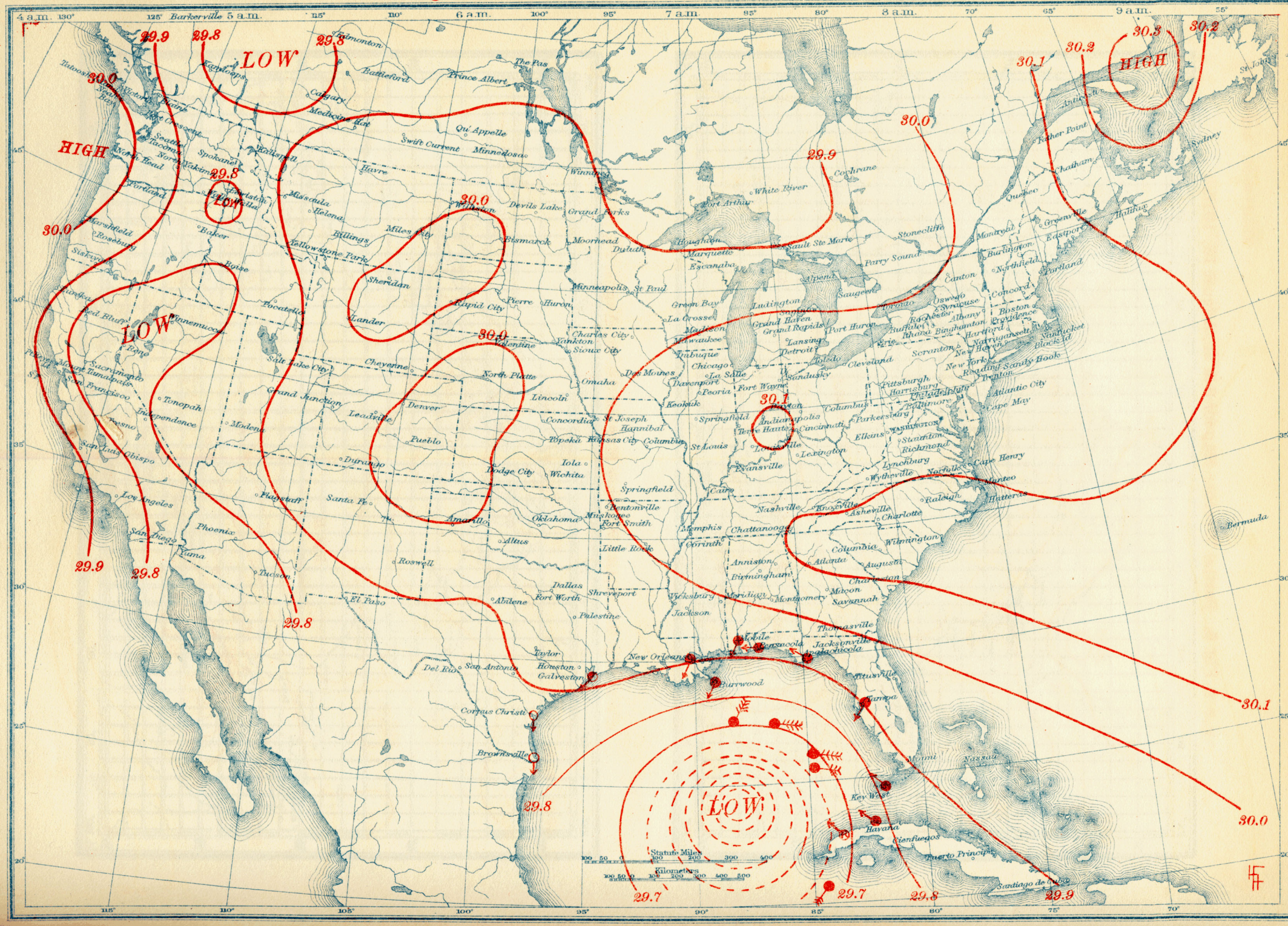
H. C. F. Fig. 5. Partial Weather Map for 8 a. m., August 13, 1915.



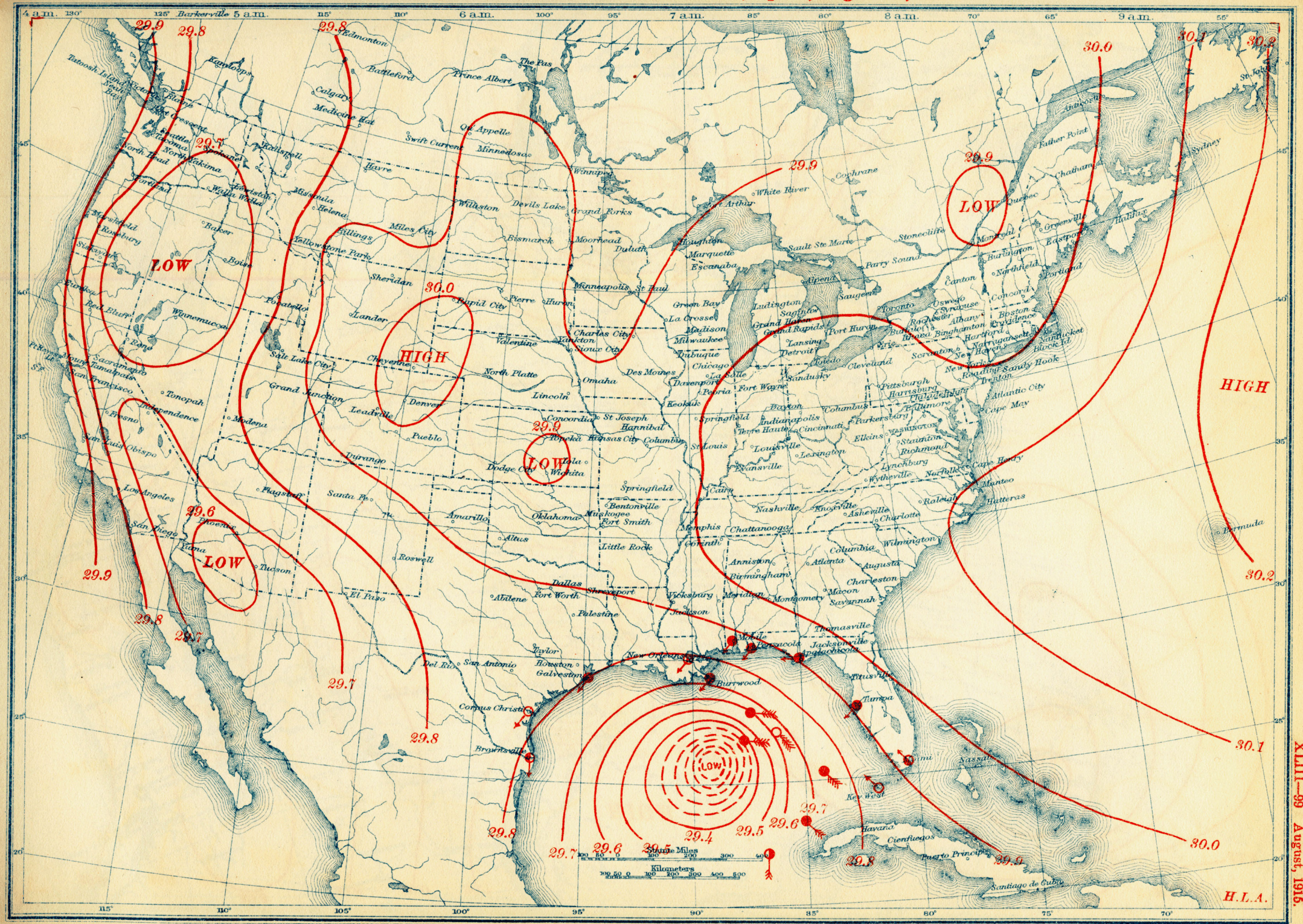
H. C. F. Fig. 6. Partial Weather Map for 8 a. m., August 14, 1915.



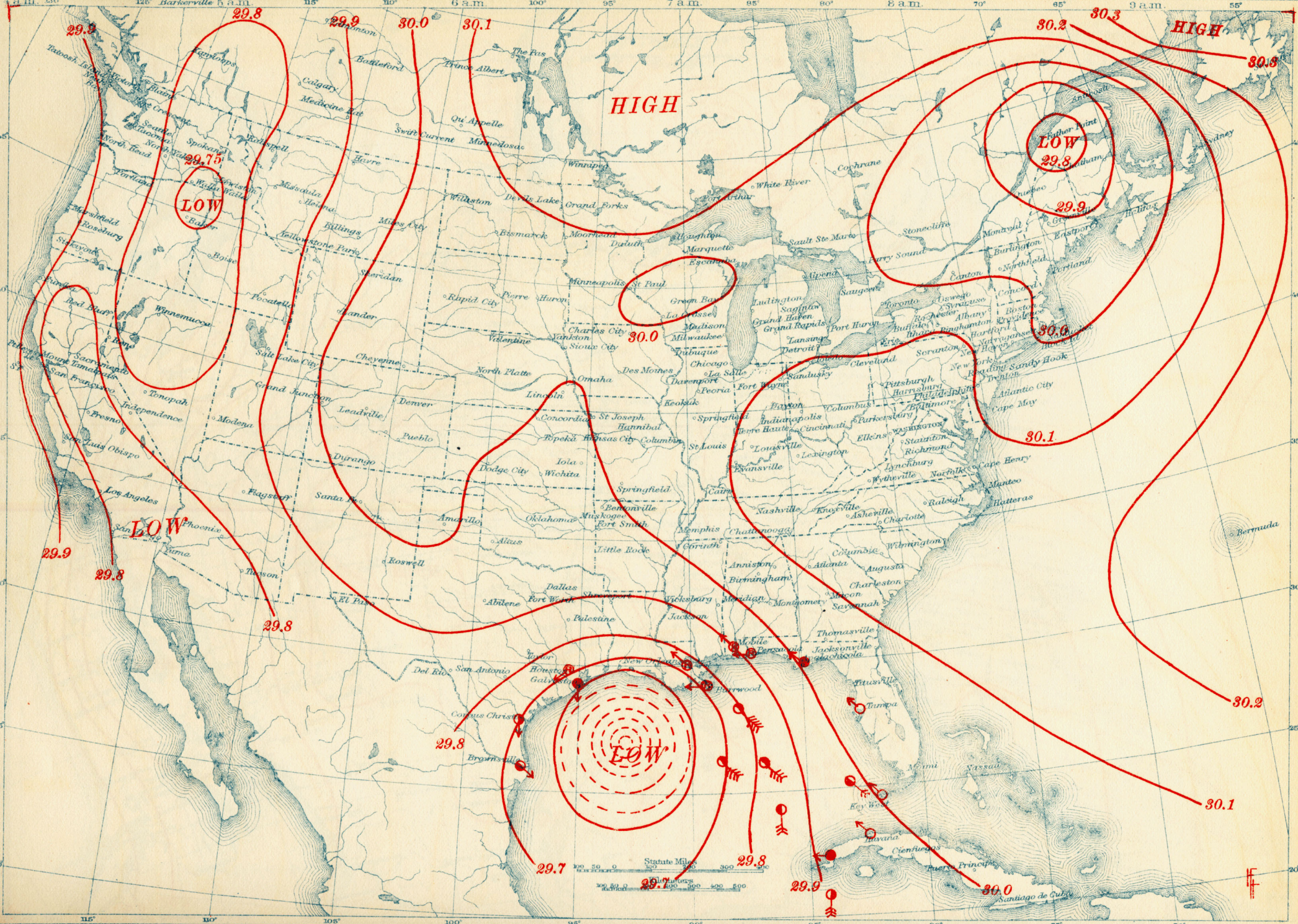
H. C. F. Fig. 7. Isobars over the United States, 8 a. m., August 15, 1915.



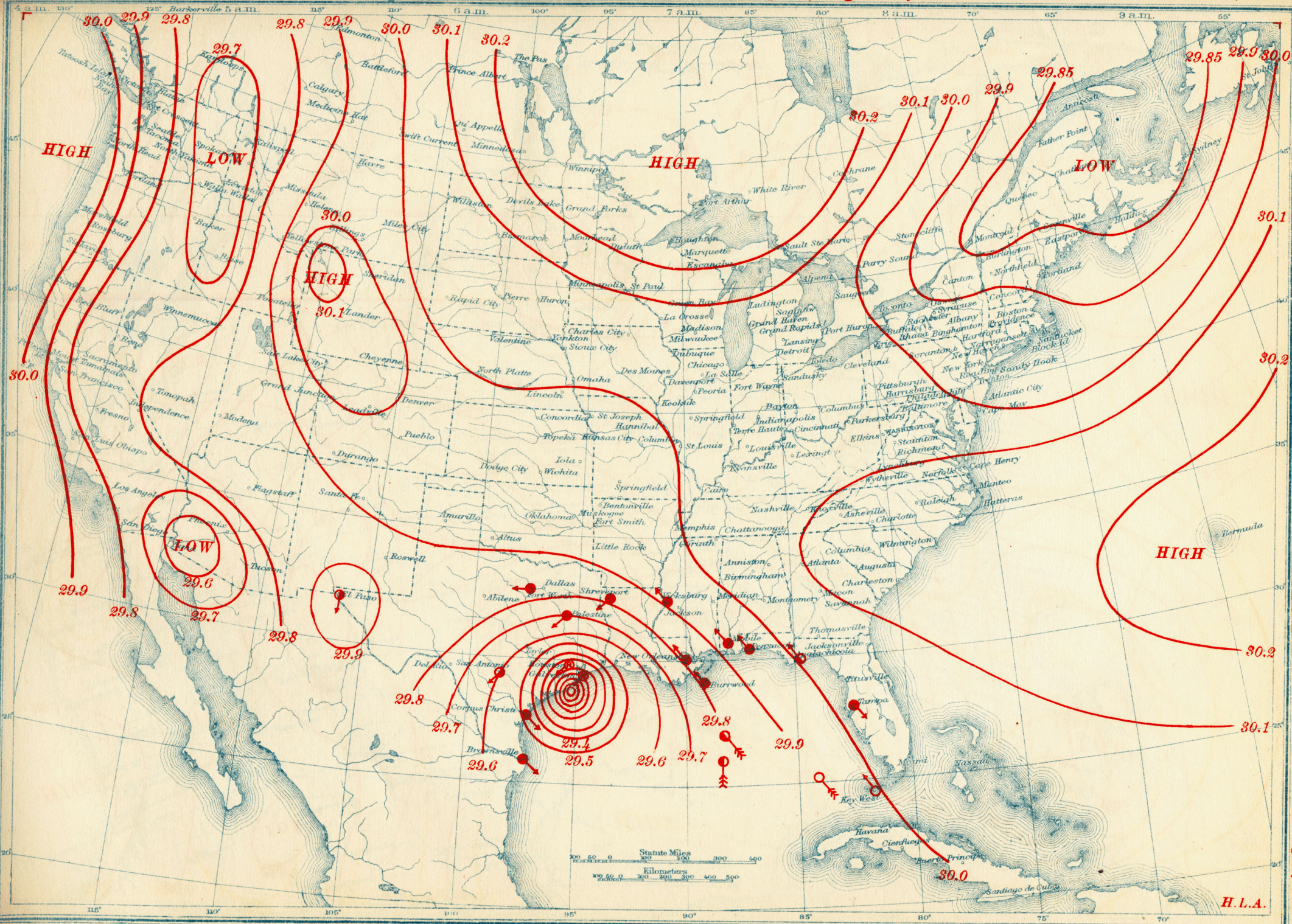
H. C. F. Fig. 8. Isobars over the United States, 8 p. m., August 15, 1915.



H. C. F. **Fig. 9. Isobars over the United States, 8 a. m., August 16, 1915.**

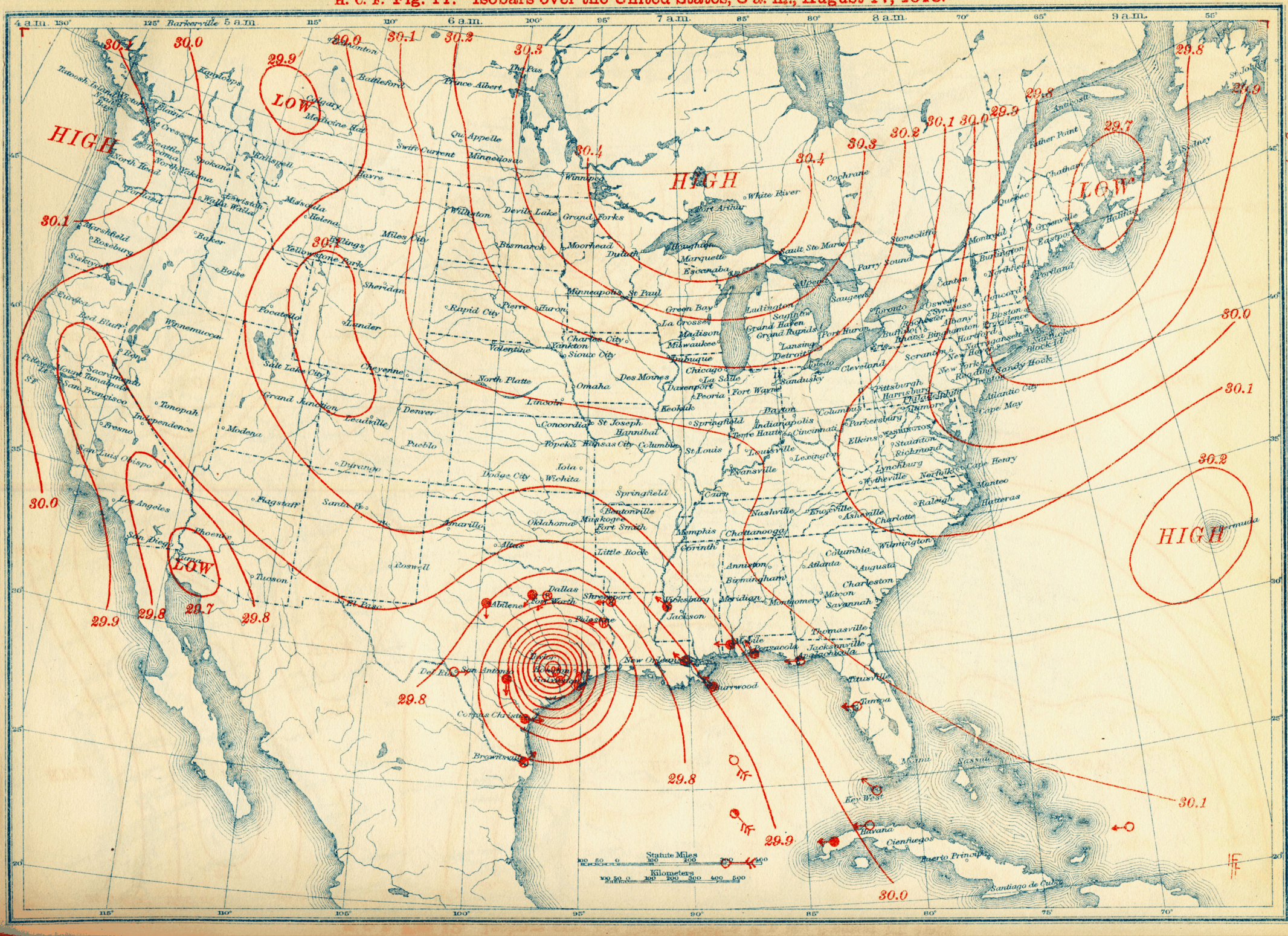


H. C. F. Fig. 10. Isobars over the United States, 8 p. m., August 16, 1915.



XLIII—101. August, 1915.

H. C. F. **Fig. 11. Isobars over the United States, 8 a. m., August 17, 1915.**



H. C. F. Fig. 12. Isobars over the United States, 8 p. m., August 17, 1915.